Heavy ion acceleration with noble metal coated large area suspended graphene: 2019-2020 Annual Report

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INTRODUCTION

Ion acceleration through laser-plasma is one of the promising technologies for realizing laboratory high energy physics, astrophysics, and table-top cancer therapy. In the target normal sheath acceleration (TNSA) configuration, protons and heavier ions can be accelerated to high energies through the strong electric field from the electron sheath. The electromagnetic field get severely attenuated beyond the skin depth when interacting with a solid target. Therefore, it is understandable that thin target is needed to achieve high ion energy. Recently, use of thin targets > 10 nm diamond like carbon film has demonstrate promising results for high energy ion acceleration [e.g., 1]. Although theoretical prediction indicated higher ion energy can be produced using a thinner target (~ 10 nm), fabrication of thinner suspended film is so far unsuccessful. Moreover, the accompany heating effect from the pre-pulse in the intense laser beam could effectively destroy the thin target before the interaction with the main laser if the thin target is not strong enough. Plasma mirrors and complicated optical path such as chirped standing wave acceleration (CSWA) configuration are usually needed to alleviate the detrimental effect from pre-pulse.

Graphene is the strongest two dimensional material. Moreover, the thickness of graphene film can be precisely controlled through chemical vapor deposition (CVD) and its subsequent transfer methods. Recently we have developed a residue free transfer method to achieve large area suspending graphene (LSG) on holey substrates [2]. Preliminary test shots on LSG with systematically varying thicknesses have been conducted in LFEX in September 2018. It was clear that the 8-layer LSG samples were strong enough to survive pre-pulse without using plasma mirror, and was able to generate energetic protons and carbon ions. Moreover, we have developed a composite target structure scheme recently. By depositing other materials on the LSG, the LSG can act as supporting scaffold for any film that can generate any kind of ions in laser plasma acceleration. In the previous LFEX experiment conducted in July 2019, we focused on the acceleration of high Z Au ions using the above scheme.

EXPERIMENT

The experiment was performed with LFEX laser facility at Institute of Laser Engineering, Osaka University from 23rd to 25th July 2019. Irradiating an LSG with two beams of LFEX laser (energy ~ 350 J per beam, wavelength 1054 nm, pulse duration 1.5 ps and focal spot ~ 30 um, providing the peak intensity of $\lesssim 10^{19}$ W/cm^{-2}), energetic ions are generated. Figure 1(a) shows a schematic image of the laser and target configuration. The LSG was irradiated from the normal incidence direction. We measured the accelerated ions with a combined stack of radiochromic films (RCF) and CR-39, and with Thomson parabola (TP). The stack was placed along the laser axis with 40 cm distance from the focal spot to the front surface of the stack. The RCFs with different sizes provide fine energy resolution. Two TP were fixed outside of the chamber and an imaging plate (IP) and MCP+CCD was used as detector respectively for respective TP. We use X-ray pinhole camera and electron spectrometer to monitor the LFEX focal spot and the electron temperature, respectively.

Figure 1(b) shows the scanning electron microscopy image of the 4-layer LSG deposited with 3 nm thick Au layer. The inset in Fig. 1(b) shows the 3 nm Au film was in the form of nano-particle layer with lateral size ~ 3 nm. Fig. 1(c) shows the Raman spectroscopy of the Au deposited LSG, indicating typical fingerprint of graphene with G band at 1580 cm^{-1}, 2D band at ~ 2680 cm^{-1}, and D band ~ 1350 cm^{-1}, probably originated from the doping effect of Au film. Besides that, a background hump in the Raman spectroscopy indicated the luminescence from Au nano-particles. Besides Au, we have mounted other material, PMMA and h-BN. We irradiate either the

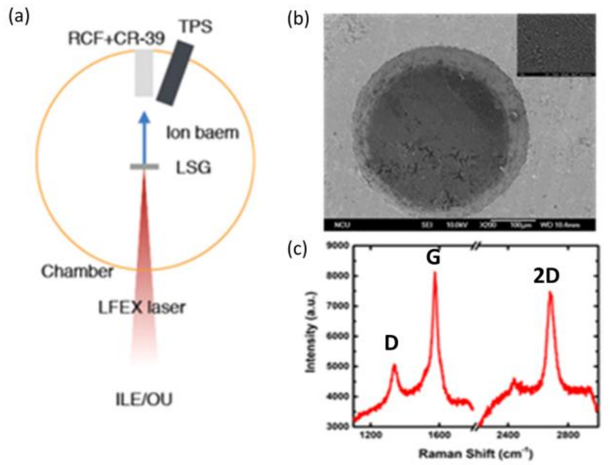

Figure 1 (a) schematics of the laser , detector, and target configuration. (b) the SEM image of the 3 nm Au deposited 4-LSG. (c) Ramam spectroscopy of the 3 nm Au/4-LSG target.

graphene side or the other material side with the LFEX laser. For instance, when we place the LSG on the laser side, we aim to accelerate the PMMA. On the other hand, when we place the PMMA on the laser side, we expect to use PMMA as fuel to accelerate LSG carbons.

RESULT

We have 9 effective shots with 4-layer LSGs and nanostructure targets suspended with LSG, where Au with different thickness from 10~100 nm, PMMA with different thickness, and single layer h-BN. Figure 2 shows the major result for successful demonstration on generation of high Z heavy ions. Figures 2(a) and 2(b) show the results with Thomson parabola spectroscopy from the shots on a 4 layer LSG deposited with 48 nm PMMA (($C_5O_2H_8$)n) and 100 nm Au, respectively. It is clear that the shot renders abundant protons, carbon oxygen ions with different charge states (C^{4+}, C^{5+}, C^{6+} and so on) in Fig. 2(a). Compared to the PMMA/LSG composite target, the 100 nm Au/LSG (4 layer LSG deposited with 100 nm Au layer) has distinctive feature in which there are tracks indicating high Z Au ions up to charge state = 51 as shown in Fig. 2(b). Theoretical calculation of laser ion acceleration considering the stripping off effect from the intense electric field of laser predicts that for laser intensity up to 10^{21} W/cm^{-2}, M shell electrons could be stripped off as shown in Fig. 2(c) [3]. However, the intensity of LFEX laser is much lower than the above estimation. Our experimental results show much higher charge state than that predicted with field ionization model. While the physical mechanism of such high ionization state is under investigation, our experiment successfully demonstrates the acceleration of high Z heavy ions (Au in this case) and the ability of LSG as a target mount for nanostructured targets.

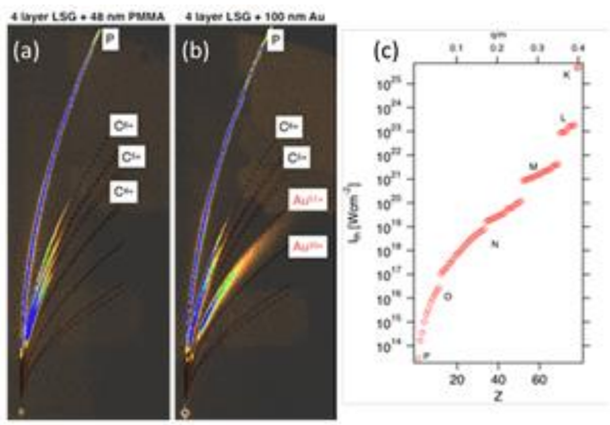

Figure. 2. (a) TPS of PMMA/4-LSG shot (b) TPS acquired for the 100 nm Au deposited 4-LSG shot. (c) Theoretical prediction for generation of ions with respective charge state.

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REFERENCE(S)

[1] I. J. Kim, K. H. Pae, I. W. Choi, C.-L. Lee, H. T. Kim, H. Singhal, J. H. Sung, S. K. Lee, H. W. Lee, P. V. Nickles, T. M. Jeong, C. M. Kim, and C. H. Nam, Physics of Plasmas 23, 070701 (2016).

[2] N. Khasanah, N. Bolouki, T.-Y. Huang, Y.-Z. Hong, W.- L. Chung, W.-Y. Woon, C.-Y. Su, and Y. Kuramitsu, High Power Laser Science and Engineering 5, e18 (2017).

[3] B. M. Penetrante and J. N. Bardsley, Phys. Rev. A 43, 3100 (1991).